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THREE PHASE SINGLE STAGE THREE-THIRTEEN LEVEL AC-DC CONVERTER

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ABSTRACT

In this paper, three phase single stage three-thirteen level AC-DC converter is presented. Multilevel converters are used in high voltage and high power applications of industry field, This converter achieves power factor correction, output voltage regulation in a single stage of power conversion, and lower total harmonic distortions by using multilevel diode clamped inverter. Increase the number of levels, the synthesized output wave form has more steps, producing a very fine stair case wave and approaching very closely to the desired sine wave and thereby the harmonics decrease, the waveforms are of high quality with a THD approaching zero. Converter description, analysis and design considerations for the proposed converter are explained.

KEYWORDS: Three Phase Single Stage Three-thirteen Level AC-DC Converter, THD

INTRODUCTION

Usage of power electronic converters are ever increasing in the processing of electrical energy in industrial applications such as uninterruptable power supply, adjustable speed drives, switch mode power supply, etc. The increasing amount urges researchers to develop more efficient, smaller size, and low cost ac-dc converters. Power factor correction (PFC) technique has been widely used in ac-dc power electronics systems. For an ac-dc converter with PFC, a common two stage PFC converter is used which consists of two power conversion stages. The front-stage is a PFC circuit followed by a dc-dc converter.

The conventional two-stage power factor correction (PFC) converters can achieve close-to-unity power factor, low total harmonic distortion (THD), and constant output voltage. There are several disadvantages of this two stage type converter, the total efficiency of the two stage is lower because the total power has to be processed twice with two cascade power stages and each power stage has to be rated as full output power which will increase the size and cost of the circuits. However, too many components are required and control circuits are complicated, which makes it less attractive in adapter applications.

To reduce the cost and increase the power density, The PFC circuit and the dc/dc power conversion circuit are combined into one stage in the single-stage PFC approach, sharing the same power switch and control circuit to perform input current shaping, electrical isolation, and tight output voltage regulation. Medium and high power ac–dc converters usually make use of continuous conduction mode boost topology as it gives near to unity power factor at the AC input. Many examples of three phase single-stage converters are proposed, however, it have at least one of the following drawbacks that have limited their widespread use.

- Sophisticated techniques, nonstandard techniques to control the converters, so the converter need variable switching frequency control methods to operate [1]–[7].
- Output ripple very high because the output current discontinuous, so the secondary diodes with high peak current ratings and large output capacitors to filter the ripple are needed [8]-[21].
- Input currents are distorted and contain a significant amount of low-frequency harmonics because the converter has difficulty performing PFC and dc-dc conversion simultaneously [11].
- Switches and bulk capacitors with very high voltage ratings are required [12]-[14].

In this paper we are using a new converter that does not have any of these drawbacks [18].

CONVERTER DESCRIPTION

The structure of the single phase single stage three level full bridge converter shown in Figure 1. consists of a three phase ac input section with an uncontrolled diode rectifier followed by the auxiliary windings taken from the converter main transformer. Then a multilevel type full bridge inverter is placed followed by the output transformer and the load. The basic principle behind the multilevel type full bridge converter is based on the combination of input inductors and auxiliary windings which carry out an action of PFC.

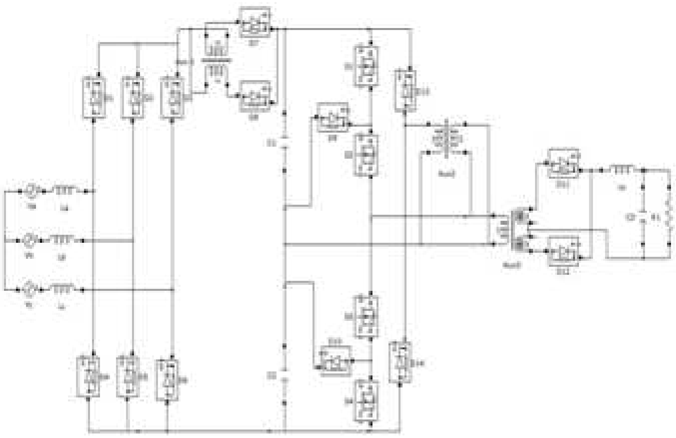

Figure 1: Matlab/Simulink Model of Existing Single-Stage Three-Level Converter

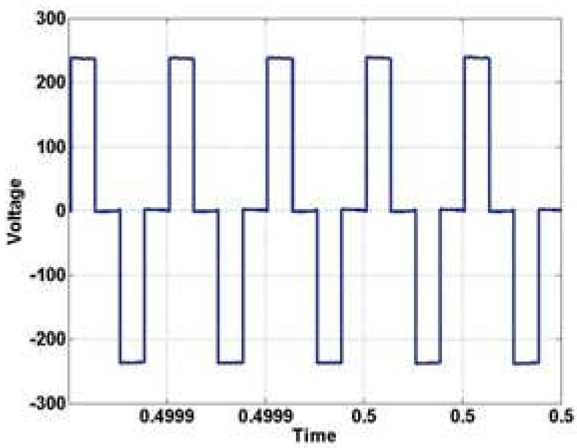

Figure 2: Line-line Voltage of the Main Transformer

Initially the rectifier which consists of six diodes is supplied by a balanced three phase voltage system. In each point two diodes of the diode bridge conduct resulting in an input current for discontinuous conduction mode (DCM) and continuous conduction mode (CCM) operation. The next section in the converter is the auxiliary windings that are taken from the converter main transformer which performs PFC by acting like a boost switch with the input inductors. Then the multilevel type full bridge inverter used for inversion. Here the bus voltage is split among the capacitors equally; thereby reducing voltage stress. By this design the flexibility of the converter is improved. As a diode clamped multilevel converter (DCMLI) is chosen because it have many advantages [22] such as:-

- When the number of levels is high enough, the harmonic content is low enough to avoid the need for filters.
- Inverter efficiency is high because all devices are switched at the fundamental frequency.
- The control method is simple.

Table 1 gives the switching sequences to generate the three-level output voltage, and this sequence can be extended to any number of levels of inverter.

Table 1: Switching Sequence for Three Level Inverter

Switch Number	Output Voltage		
	+Vdc/2	Zero	-Vdc/2
Switch 1	1	0	0
Switch 2	1	1	0
Switch 3	0	1	1
Switch 4	0	0	1

From table 1 It can be seen that the converter goes through the following modes of operation in the switching cycle:-

- Switches S1 and S2 are ON. Energy from the dc link capacitor C1 flows to the output load, Due to magnetic coupling, a voltage appears across one of the auxiliary windings and cancels the total dc bus capacitor voltage; the voltage at the diode bridge output is zero, and the input currents rise.
- The primary current of the main transformer circulates through D9 and S2, D10 and S3 and the output inductor current freewheels in the secondary. There is no energy transferred to the dc bus capacitors.
- Switches S3 and S4 are ON; a symmetrical period begins. In this mode, energy flows from the capacitor C2 into the load. The voltage across the auxiliary inductors becomes only the rectified supply voltage of each phase, and the current flowing through each inductor increases.

The waveform of line-line voltage of the main transformer as shown in Figure 2 describing the modes of operating of the three level output voltage (+Vdc, Zero, -Vdc).

Various techniques for capacitor voltage balancing to ensure the voltage across each bus capacitor is the same, have been proposed in the literature, including techniques that sense the capacitor voltages and adjust the duty cycle of the converter switches appropriately. For this work, an additional transformer with a turns ratio of 1:1 and two fast recovery diodes are required to realize the technique [17], which are used to assure equal voltage across the capacitors. This circuit is very simple, small, and handles only a small fraction of the overall power that is processed by the converter so that the low current rated diodes can be used (<1A) and a small core can be used for the transformer. The basic principle behind the

auxiliary circuit is that if the voltage across one capacitor begins to be greater than the other by more than a diode drop, then one of the diodes begins to conduct as energy is transferred away from the capacitor with the higher voltage. Since the auxiliary circuit does not allow for large differences in bus capacitor voltage, the amount of energy that needs to be transferred away at any given time is small. When the auxiliary circuit is added to the main circuit, It forces a diode to conduct thereby dissipating energy, when a difference in voltage is noted. By this means capacitor voltages are being balanced.

ANALYSIS OF THIRTEEN LEVEL DCMLI

A multilevel structure with more than three levels can significantly reduce the harmonic content. By using voltage clamping techniques, the system KV rating can be extended beyond the limits of an individual device. The main feature of the multilevel inverter structures is their ability to scale up the kilovolt-ampere rating and also to improve the harmonic performance greatly without having to resort to PWM techniques[22]. The key features of a multilevel structures as follow:

- The output voltage and power increase with number of levels, Adding a voltage level involves adding a main switching device to each phase.
- The harmonic content decreases as the number of levels increases and filtering requirements are reduced.
- With additional voltage levels, the voltage waveform has more free-switching angels, which can be preselected for harmonic elimination.
- In the absence of any PWM techniques, the switching losses can be avoided. Increasing output voltage and power does not require an increase in rating of individual device.
- Static and dynamic voltage sharing among the switching devices is built into the structure through either clamping diodes or capacitors.
- The switching devices do not encounter any voltage-sharing problems. For this reason, multilevel inverters can easily be applied for high-power applications such as large motor drives and utility supplies.
- The fundamental output voltage of the inverter is set by the dc bus voltage, which can be controlled through a variable dc link.

The only disadvantage of the multilevel converter is that it required a huge amount of semiconductors switches. It should be pointed out that lower voltage rated switches can be used in the multilevel converter and as a result the active semiconductor cost is not considerably increased when compared with the two level cases. On the other hand, each active semiconductor added requires associated gate drive circuitry and adds further complication to the converter mechanical layout. Another disadvantage which is to be mention is that the small voltage steps are typically formed by isolated voltage sources or a bank of series capacitors. Isolated voltage sources may not always be readily available and series capacitors require voltage balance. To some extent, the voltage balancing can be addressed by using an uncalled-for switching states, which exist due to the high number of semiconductor devices. Nevertheless, for a complete solution to the voltage-balancing problem, another multilevel converter maybe is required.

MATLAB/ SIMULINK MODELINK AND SIMULATION RESULTS

Three phase single stage thirteen level converter is simulated in MatLab/ Simulink Software. A three phase source

with a line to line rms voltage of 208 is connected with the input inductors (Lin) 60 μH, This value of Lin should be low to assure input current to be fully discontinuous but not very low value leading to high peak currents. Then the auxiliary windings are taken from the multi winding transformer block in MatLab. They are connected in an indirectly coupled fashion. The other end of the winding is connected to the full bridge converter of multilevel type.

This converter consisting of twenty four MOSFET switches which are connected in a diode clamped inverter with twenty two diodes and twelve capacitors. Next is the main transformer whose turns ratio is 3:1. The thirteen level voltage is rectified using the transformer and then is filtered using an LC filter .The value of output inductor (Lo) is designed such that it results in a low ripple at output and low peak current rating for secondary diodes. The value of Lo chosen is 11 μH. Figure 3 Show the proposed converter.

Typical converter waveforms are shown in Figures 4-12 which are shows the (Input current and voltage, Output regulation voltage, Line-line voltage of the main transformer (13 level), Output inductor current, Power factor measurement, DC link voltage (Vdc), Capacitor voltage, Switches voltage, Total harmonic distortion THD) for the three phase single stage thirteen level converter. This converter was designed according to the following specifications:-

Input voltage Vin= 208 Vrms (line-line) Output voltage Vo= 48 v

Output power Po= 1.5 Kw Switching frequency f_{sw}= 50 KHz

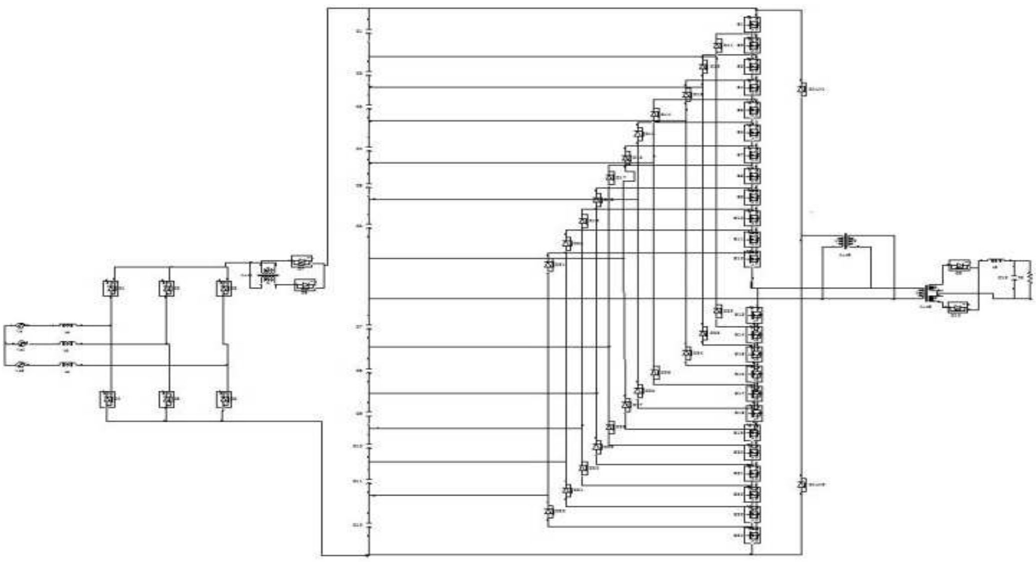

Figure 3: Matlab/ Simulink Model of Proposed three Phase Single Stage Thirteen Level AC-DC Converter

This converter is simple (topology and capacitor voltage balancing), and can operate with less output inductor current ripple, operate with no dead band regions, the switch stress is half the dc bus voltage. The proposed converter has low THD, which is better than the converters in [12] [13] [18].

A comparative study of three, five, seven, nine, eleven, thirteen level diode clamped inverter has been presented in the table 2. Simulation results indicated reduction in total harmonics distortion (THD) by using higher number of level.

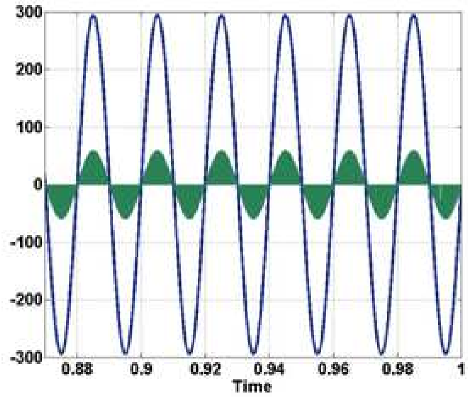

Figure 4: Input Current and Voltage (V: 100 V/div 1:10 A/div

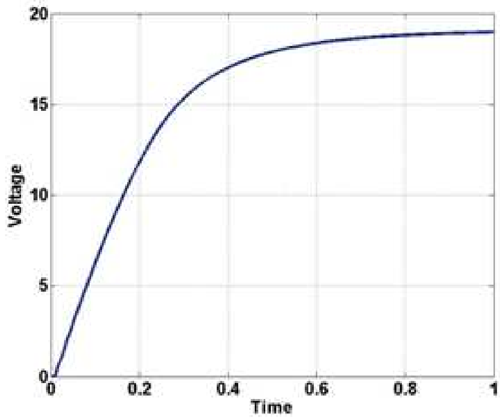

Figure 5: Output Regulation Voltage (V. 5V/div, t: 0.2s/div)

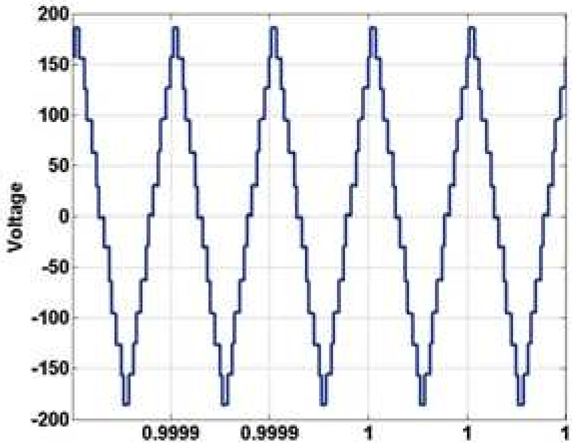

Figure 6: LineLine Voltage of the Main Transfer (V.50 V/div., t 30us/div)

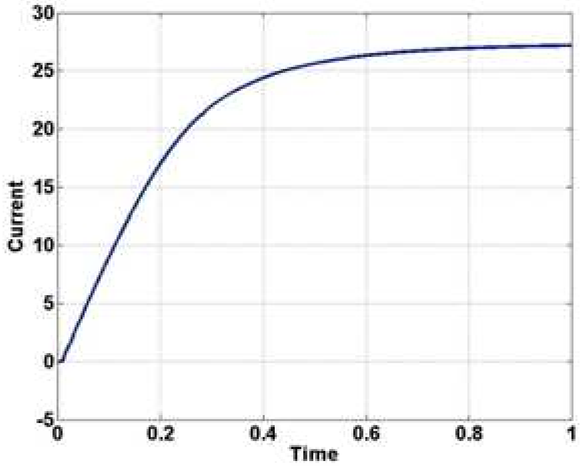

Figure 7: Output inductor Current (I=5A/div, t 0.2s/div)

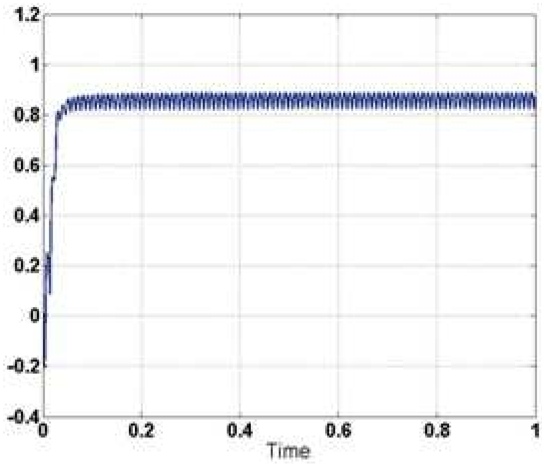

Figure 8: Power factor Measurement 0.86

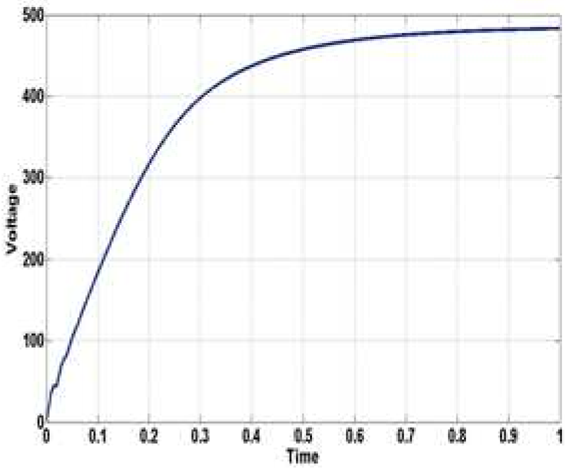

Figure 9: DC Link Voltage (Vdc) (V: 100 V/div, t 0.1s/div)

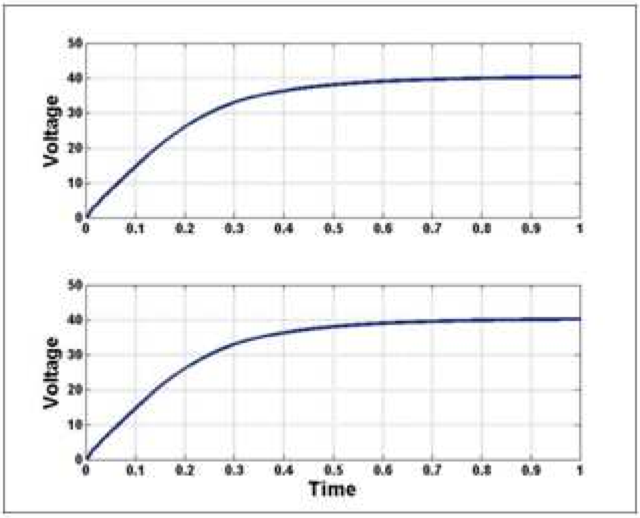

Figure 10: Capacitor Voltage (V: 10v/div, t 0.1s/div)

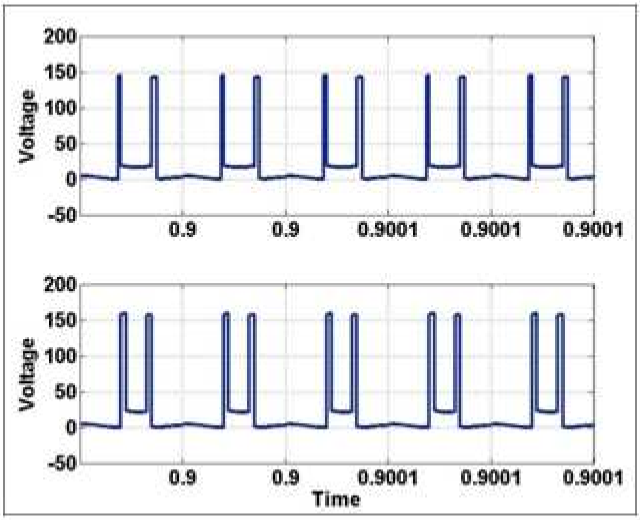

Figure 11: Bottom Switch Voltage Vds8 and vds9 (V: 50 V/div, t: 20 us/div)

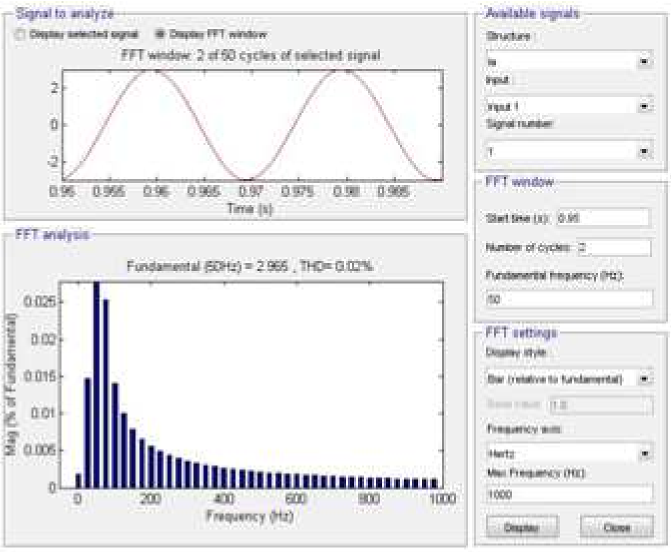

Figure 12: Total Harmonic Distortions, 0.02%

Table 2: Comparison of Different Topologies between Different Level

Topology	Number of level					
	3	5	7	9	11	13
No. of switches	4	8	12	16	20	24
No. of clamping diodes	2	6	10	14	18	22
No. of dc bus capacitors	2	4	6	8	10	12
THD %	0.82	0.62	0.41	0.2	0.06	0.02

CONCLUSIONS

A three phase single stage, three level, thirteen level, ac to dc converter is simpler in terms of topology with very less distortion and high power factor is presented in this paper along with the simulation results. The proposed inverter can generate thirteen levels at the output with THD of only 0.36%. Due to simple modulation strategy, the control of inverter is easy. It is simple in capacitor voltage balancing and can operate with less output inductor current ripple, even continuous output inductor current. It is operated with lower peak voltage stresses across the switches and the dc bus capacitors as it is a multilevel converter. This allows for greater flexibility in the design of the converter and ultimately improved performance. The corresponding simulation results for the proposed topology are shown for a 1500W system.

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